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ON THE COVER:

This is perhaps an excusable exercise in staged picture taking in order to display AFCRL-grown crystals being studied by a pretty secretary. The crystals, grown in a Verneuil furnace, are a variety of aluminum oxides for possible laser application. The different configurations of the crystal boules resulted from changes in the growth rate. The secretary is Colleen Loiselle of AFCRL's Solid State Sciences Laboratory.

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JACOB SEIDEN *Editor*

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measurement of the complex dielectric constants of materials in the microwave-optic region

DR. PAUL D. COLEMAN, Electro-Physics Laboratory, University of Illinois

In searching for data on the dielectric properties of materials in various regions of the spectrum, one can readily find a wealth of information in the range from 100 Hz to 25 GHz (1) and a large amount of data in the optical and infrared range out to around 25 microns wavelength. (2) Above 70 GHz and beyond 25 microns, the amount of data on materials decreases rapidly. This situation is a result of the fact that, until recently, the only sources of radiation available for use in measurements were noncoherent blackbody radiators or weak coherent harmonic signals generated via lower-frequency electronic tubes.

The recent development of molecular lasers (3,4) (for example, H_2O and HCN) now provides over 100 lasing lines from 16 to 774 microns while experimental carcinotron tubes (5,6) have been extended down to 296 microns wavelength from the microwave side. Thus for the first time, in 1966-67, the far-infrared gap has been bracketed with strong coherent sources from both the optical and microwave sides of the spectrum. Some 3 kilowatts of pulsed power are available at 28 microns in a modest-sized H_2O laser, (7) for example.

It is the purpose of this article to describe a portion of the research of W. Block, D. Keune, and H. Sievering of the Electro-Physics Laboratory, University of Illinois, (with AFOSR support) in making use of these new coherent laser and tube sources, along with photoconductive (Gu:Ge, Ga:Ge, InSb) and semiconductor diode detectors, to measure the complex dielectric constant of materials in this previously difficult spectral region.

The dielectric property of a material is conveniently characterized by expressing the complex propagation constant γ of a plane wave propagating through the medium in the form,

$$\gamma = \alpha + i\beta = i\frac{\omega N}{C} = i\frac{\omega (n - ik)}{C}$$

$$= i\omega\sqrt{\mu\epsilon} = i\omega\sqrt{\mu\epsilon'(1 - i\tan\delta)}. \quad (1)$$

Here α is the attenuation constant, β the propagation constant, ϵ the complex dielectric constant, with ϵ' the real part and $\tan\delta$ the loss tangent, μ the magnetic permeability, N the complex index of refraction, n the real index of refraction, K the absorption index, ω the angular frequency and t the time.

The measurement schemes used to determine complex γ, ϵ or N are all optical methods involving the reflection and transmission of usually polarized plane waves through sheets, prisms, lens, etc., of the material. Interference phenomena due to multiple reflections within the material tend to make the formulas for the case of loss to be rather complex.

The measurement technique used by Block with the carcinotron tubes in the 0.35-to-4-millimeter-wavelength range is a Fabry-Perot resonator method (8) shown in Figure 1. The mathematical equations are simplified if the dielec-

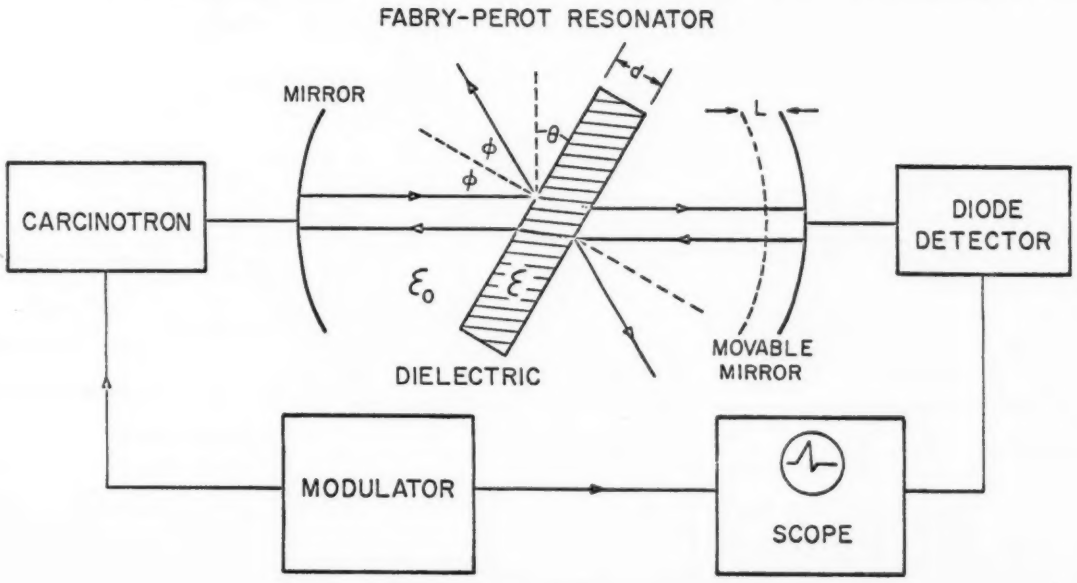

Figure 1. Carcinotron—Fabry-Perot resonator method.

tric sheet is tilted at a slight angle θ to allow the reflected waves from the dielectric-air interfaces to escape the resonator. Introduction of the dielectric sheet shifts the frequency of a given TEM_{00q} mode. The frequency can be restored by moving one plate of the resonator a distance L until the "pip" on the scope returns to its original position.

To a first approximation, the index of refraction is given by the expression

$$n \simeq 1 + L/d, \qquad (3)$$

where d is the dielectric sheet thickness.

The absorption index K or the loss tangent tan δ can be determined in a somewhat tedious manner from a measurement of the Q of the resonator with and without the dielectric sheet. Accuracy on the measurement of n is slightly less than 1% while accuracy of tan δ is of the order of 10% for typical materials. The size of the dielectric sheet required is of the order of two or three times the resonator beam area ($b\lambda_0/2$), where b is the mirror separation and λ_0 the free space wavelength.

The measurement scheme (9) used by Keune with the molecular-laser source in the range 0.016 to 0.774 millimeters wavelength is illustrated in Figure 2. Single-frequency operation of the laser is achieved by using a rotatable reflection grating in place of a flat mirror in the laser resonator. The radiation is polarized by means of a wire grid rather than a Brewster angle window.

The real part of ϵ' of the dielectric constant is determined by rotating the sample to the pseudo-Brewster angle θ_B where the reflection is minimum, while the loss tangent is found by measuring the transmission of the sample at the angle θ_B.

The noncoherent source measurement system used in the past before the advent of the molecular laser and carcinotron tube employed a grating monochromator or an interferometer. (10) This is also the scheme used by Sievering. The resolution of both of these instruments was essentially source-detector limited, but in principle the interferometer can yield greater resolution with sufficient mirror scan and computation. The monochromator designed in the Electro-Physics Laboratory by R. Roldan is shown in Figure 3. It is a familiar on-axis Littrow system, using a 16 X 16-inch aluminum reflection grating with a low-pass filtering system on the input to strongly suppress the black-body radiation from the Hg arc lamp below 100 microns wavelength. The sheet-material sample to be measured can be placed anywhere in the light pipe leading from the exit slit to the detector.

The index of refraction n of an isotropic sheet of material of thickness d (where $d \leq 20\ \lambda$) is found by studying the interference effects in the sheet as the wavelength is varied. As the electromagnetic waves reflect back and forth within the sheet, they cause the transmitted wave to be periodically varied in intensity as the wavelength changes. Knowledge of the minimums permits one to calculate n from the so-called channel spectrum.

The absorption index K is determined by using a thicker sample, for which the monochromator cannot resolve the channel spectrum, and measuring the average transmission.

In principle the monochromator shown can operate from the visible to the order of 1,000-micron wavelengths.

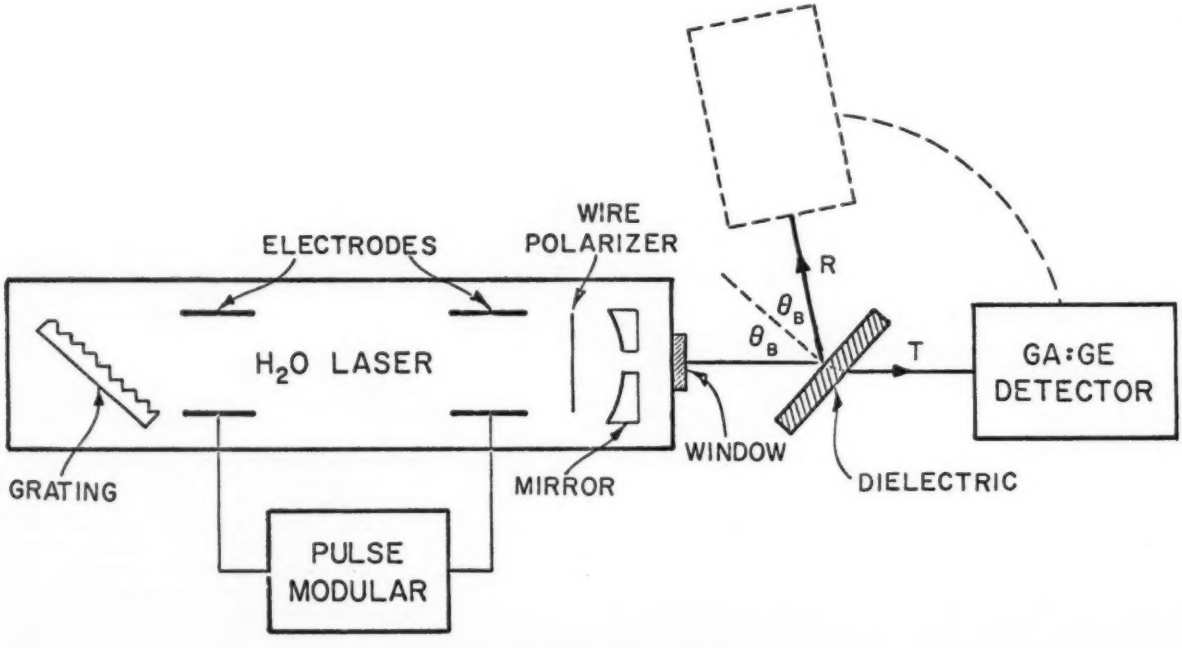

Figure 2. Molecular laser—Brewster angle method.

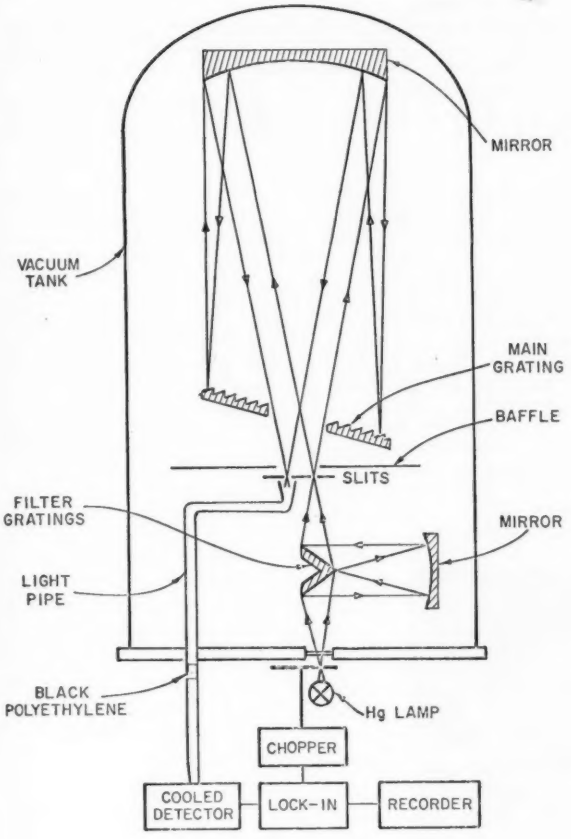

Figure 3. Reflection-grating monochromator.

However, since 16 X 16-inch gratings become difficult and expensive to make for wavelengths below 100 microns, our instrument is typically used in the 100-to-1,000-micron range. Thus it covers the overlap region between the molecular lasers (16 to 774) and the carcinotron tubes (280 to 4,000 microns).

Figure 4 gives some initial data obtained by Block, Keune, and Sievering on polyethylene, a material used both in the infrared and microwave regions.

The conclusions that we would like to draw at this time are that techniques, sources and detectors exist to measure the complex dielectric constants, at almost any given wavelength from 30 to 3,000 microns, of materials which can be obtained in chip or sheet form. In the 280-to-774-micron range, the three sources and methods used overlap and provide a cross check on one another.

The knowledge of the dielectric constants of materials in the far-infrared is necessary for device designs, Brewster windows, lens, detector windows, beam splitters, laser windows and mirrors, polarizers, and host materials for other dopants. Extension of the techniques to the study of resonances, photoconductors, anisotropic and electro-optic materials, nonlinear effects, and liquids are readily within reach. It is believed that, with the new coherent sources and detectors, the colonization of the far-infrared can proceed rapidly in the near future.

The author is indebted to Dr. Marshall Harrington and Capt. John Kantak of AFOSR and to Mr. Richard Davis of the Rome Air Development Center for their support and interest on various phases of the problem.

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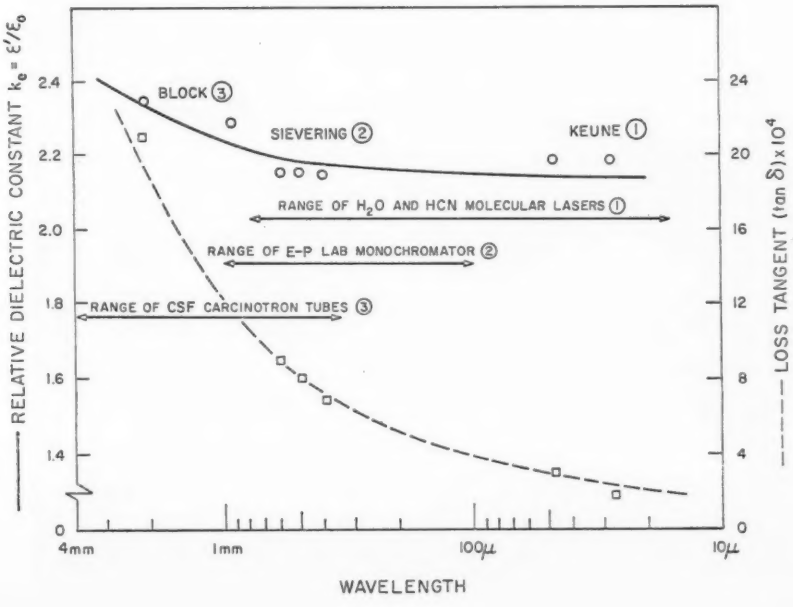

Figure 4. Far-infrared dielectric property of polyethylene.

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Dr. Paul D. Coleman is the director and founder of the Electro-Physics Laboratory in the Department of Electrical Engineering, University of Illinois, Urbana, Illinois. He has been active in millimeter, submillimeter, and far-infrared physics problems ever since completing his Ph.D. dissertation in physics at the Massachusetts Institute of Technology in 1951. Since coming to the University of Illinois, his research interests have included megavolt electronics, Cerenkov radiation, dipolar modes in ferrites, reflecting beam waveguides, frequency multiplication, molecular and chemical lasers, and the far-infrared optical properties of materials. For a large portion of this work, he has received AFOSR support.

Dr. Coleman is a Fellow of the IEEE, having received the award for his work on millimeter waves. He is also a member of the American Physical Society.

Dr. Coleman (right) is shown with one of his graduate students, Richard Mayeur, assembling a molecular laser.

A NEW MATHEMATICAL JOURNAL ON APPROXIMATION THEORY

DR. O. SHISHA, Applied Mathematics Research Laboratory, ARL

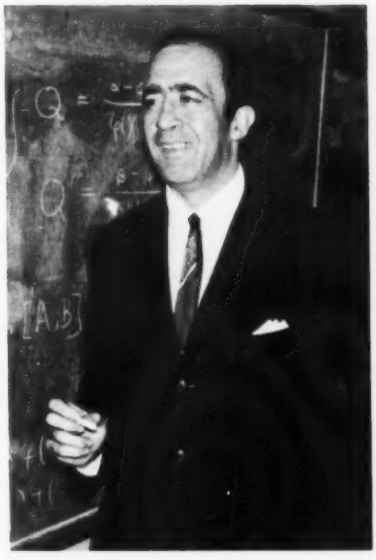
Approximation theory is a mathematical field which has recently undergone an unusual revival. It is an old discipline, and many of its central theorems were proved in the 19th century. However, due to the development of high-speed electronic computers, interest in this field has very noticeably increased during the last years.

Approximation theory is a mathematical branch dealing with the approximation of arbitrary, general functions by simple ones. Since many of the functions encountered in mathematics are too complicated to be handled in applications, a need arises to substitute simple approximations for these functions. This explains the importance of approximation theory in the application of mathematics to science and technology. Approximation theory is, however, also an important mathematical area in its own right, possessing many fascinating problems, methods, and results.

To help mathematicians working in this area communicate their ideas and results, a new journal, *Journal of Approximation Theory*, has been founded. It will shortly commence publication, its publisher being Academic Press. Its founder and editor is O. Shisha of the Applied Mathematics Research Laboratory, Aerospace Research Laboratories, a component of OAR. The *Journal* has 19 associate editors, including most of the main workers in the field in the United States, as well as a number of distinguished European mathematicians.

This *Journal* will be devoted to the basic theoretical aspects of approximation theory. It will publish papers in approximation theory and in related topics, as well as papers which treat significant applications or which produce valuable insights into approximation theory. Papers relating to numerical work will definitely be encouraged, provided their level and importance would justify it. Criteria for publication will include novelty, importance, and clarity of presentation.

Dr. Oved Shisha has been a research mathematician with the Applied Mathematics Research Laboratory, ARL since 1962, working in approximation theory and in other areas of mathematical analysis as well. He received his M.S. in 1955 and his Ph.D. in 1958, both in Mathematics and both from the Hebrew University, Jerusalem, Israel. From 1955 to 1958, he was an instructor at the Technion – Israel Institute of Technology. From 1958 to 1960, he was a research fellow at Harvard University, and from 1960 to 1962, he was employed as a mathematician at the National Bureau of Standards. Dr. Shisha is co-editor of the book, Studies in Approximation and Analysis, published in 1966 by the Society for Industrial and Applied Mathematics, Philadelphia, Pa. He is a member of Sigma Xi, the Ohio Academy of Science, and the Israeli Mathematical Union. He has published a great number of research papers.



Dr. Shisha working on approximation theory at the blackboard.

new instrument for density measurements

AEROSPACE INSTRUMENTATION LABORATORY, AFCRL

AFCRL has redesigned conventional instrumentation for making upper-atmosphere-density measurements for use in a small meteorological sounding rocket. The density-measuring technique was previously used only in large costly rocket probes. The instrument combines an ionization pressure gauge and a pitot tube of the type used to sense aircraft speed. The instrument uses a radioactive agent (americium 241 of about two millicuries) to ionize neutral atmospheric gases. The ionized gas sets up a current flow which can be interpreted in terms of atmospheric density. The instrument is useful for measuring atmospheric density at altitudes between 30 and 100 km. It was flown successfully on a Sparrow Arcas rocket on February 8, 1968, with a second successful flight being completed on the following day. For successful operation, the speed of the rocket must maintain supersonic velocity, and the angle of attack relative to the flight path must be within 10 degrees. The redesigned density instrumentation for use in smaller rockets offers advantages in cost and simplicity over other density sensors. The sensor was developed jointly by Gerald A. Faucher and James F. Morrissey of AFCRL, and personnel from the University of Michigan.

DR. WARD C. ROMAN
Thermomechanics Research Laboratory, ARL

ELECTRODE EROSION FROM HIGH-CURRENT MAGNETICALLY DRIVEN PLASMA ARCS

The development of plasma-arc heaters for re-entry wind tunnels is limited mainly by electrode lifetimes. Electrode erosion leads to the primary failure mode in addition to undesirable contamination. Therefore, most arc-heater designs use water-cooled copper electrodes with a magnetically driven arc in order to limit erosion.

A cooperative ARL/Convair study is being conducted to find the mechanisms responsible for electrode erosion and, thereby, to discover ways to minimize electrode attrition. A typical arc-heater geometry employing magnetically driven arcs on cooled metal electrodes is duplicated in the described experiments.

Figure 1 shows the experimental arrangement. The arc current and magnetic field are pulsed from capacitor banks. The arc is driven along the rail electrodes by a uniform transverse magnetic field of up to 8 kilogauss (the self-magnetic field effects have been minimized). The arc-current range is from 2 to 30 kiloamperes, with gas pressures of from 1 to 4 atmospheres. High-speed color photos of the moving arc are achieved using electronic delay units and 10^6 frames/sec cameras.

Test samples, in the form of metal plates, are placed between the rail electrodes (1.8 cm apart) so that they are traversed by the traveling arc and simultaneously show the cathode and anode attachment areas.

The first portion of a detailed parametric study of the most important parameters influencing electrode erosion has been completed. The results indicate that erosion increases significantly as gas pressure is increased, as the driving external magnetic field is decreased, and as gases are changed in the following order: argon, nitrogen, helium, and hydrogen. In addition, surface films have a strong influence on electrode erosion. (Arc prefers an attachment to an oxidized surface.) Arc current and electrode gap were found to have secondary influence. The high-speed photos indicate that the arc attaches in one or several parallel attachment spots at the anode and cathode. The dwell time of these spots ranges from 1 - 20 μsec on copper electrodes. The erosion tracks left on various metals (e.g., tungsten, rhenium, tantalum, copper) after a single passage of the arc traveling at 230 m/sec were compared. Erosion was heavier at the anode than at the cathode. Thin coatings of rhenium on copper show promise for increased erosion resistance.

The work performed at Convair by Dr. Rolf Dethlefsen, under contract to ARL, is continuing with more detailed studies of the time history and dynamics of the arc-attachment regions and the attachment mechanism.

To extend this parametric study to the very-high-pressure regime, a unique high-pressure plasma-arc test facility has been assembled. Initial testing is under way at ARL. These tests will concentrate on the 1-200 atmosphere regime because of the relevance to ultrahigh-pressure arc heaters and high-power light sources. A novel closed-loop configuration is used which permits an accurate balance of gas and water pressure throughout the entire operating pressure range. Thus, configurations using electrodes of extremely thin walls, with their accompanying high heat-transfer rates, are feasible. The electrode

geometries to be tested include pin, rail (direct correlation with Convair results), and coaxial-cylinder types. The range of test parameters, for steady-state and transient operation, are the following: arc current 0.1 to 5 kiloamperes, magnetic-field strength up to 10 kilogauss, and pressure up to 200 atmospheres. Copper and tungsten electrodes will be used in argon and nitrogen environments.

The experimental findings of the ARL/Convair studies are to be compared with the recent results of an ARL analytical heat-transfer study of the arc attachment, including the transient effect. Very little research in the past has gone into studying the mechanism of attachment, the accompanying physical properties at the anode surface, and the transient heat-transfer phenomena. Prior investigations have treated the quasistationary case whereas, with the extremely short dwell times and the high local heat fluxes encountered, the transient effects become significant. The values for heat flux, electrode thickness, material properties, and arc spot size and dwell times are taken from experimental findings.

The results to date indicate that an electrode thickness may be chosen to optimize the thermal response of the electrode for given input conditions of heat flux and dwell time.

The results of this cooperative research effort may lead to an optimum electrode design and to a more complete understanding of the arc-attachment mechanism.

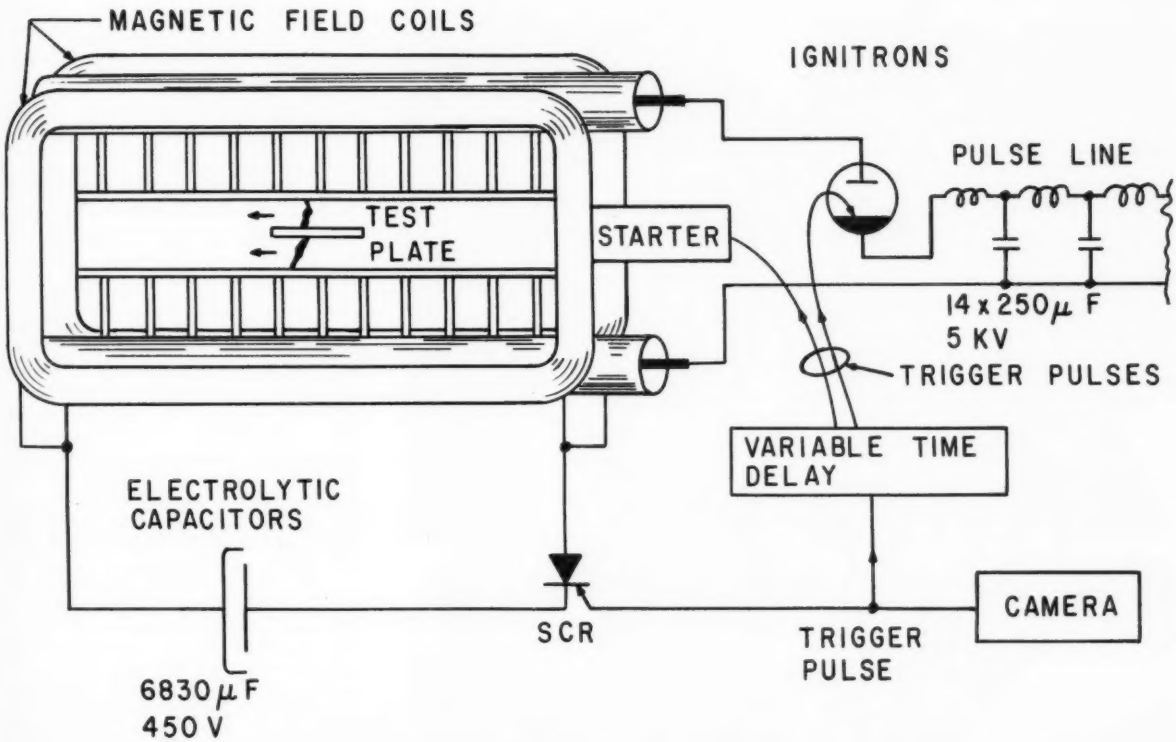


Figure 1. Schematic setup for the pulsed travelling arc.

detecting and correcting errors

DATA SCIENCES LABORATORY, AFCRL

This item is intended to highlight the development at AFCRL of new encoder-decoder equipment to implement a very efficient code for detecting and correcting errors in a string of binary digits. The particular code around which the equipment was designed was also developed by an AFCRL scientist. With this fact established, let's say something about the transfer of binary digits. We'll start with an example that may illuminate the subject, even though it is somewhat far afield.

When we read that a little old lady in Dubuque has received a $1,000,000 Social Security check instead of her expected $100, we can assume several possible sources of error—a bit of missing oxide on a computer memory tape, some transient in the transmission line from computer to automatic printer, or a rare failure in the coding scheme designed to detect errors. But basically, in the short, clean, noiseless computer channels through which the torrent of digits flow, there is only small likelihood that a zero will be erroneously transformed into a one or that a digit is dropped or spuriously inserted. The occurrence is so rare in computers that only a very simple code is needed (if at all) to detect possible errors.

However, where certain kinds of digital data must be sent over channels that are noisy and imperfect, and it is essential that the digits received be precisely those that are sent, automatic error-detecting and -correcting codes must be used. Such codes consist of a string of information bits followed by a number of code or parity check bits. For example, four information bits may be followed by three parity bits which can detect and, to some extent, correct errors in the four information bits. There can be an infinite number of codes—and many thousands in several major code classes have in fact been developed. The development of a good code, like an exercise in cryptography, requires mathematical logic, patience, and often spontaneous and creative insight.

As a measure of the mathematical complexity of these codes, it should be noted that, once a good code is discovered, there is no easy way of judging, except in a qualitative way, just how efficient it is. Nor is there any way of comparing the efficiency of one good code against that of another good code. (An efficient code is one that can detect and correct errors using a small number of parity bits relative to information bits.) In his classic paper, "Mathematical Theory of Communication," Claude Shannon, in 1948, dealt with these considerations. He proved that a great treasure of optimum codes exists theoretically; but his theorems provided no map to this treasure. Many people are trying to find optimum codes that are known to exist. While many good codes have been found and put to use, optimum codes have eluded discovery.

Several years ago, Eugene Prange (then of AFCRL) developed a powerful new class of cyclic codes now widely recognized for their efficiencies. One code in this class consists of 45 information bits followed by 28 parity bits. (The development of an efficient code is one thing; the design of associated automatic encoder-decoder equipment to implement it is another.) A great advantage of the Prange code is that it is relatively easy to implement through the design of equipment to encode and decode the string of digits. Since the code was developed, AFCRL has experimented with encoder-decoder schemes for implementation by means of computer simulation. Favorable computer results prompted AFCRL to build a breadboard model, including a decoder based on a new decoding algorithm invented by Charles F. Hobbs of AFCRL.

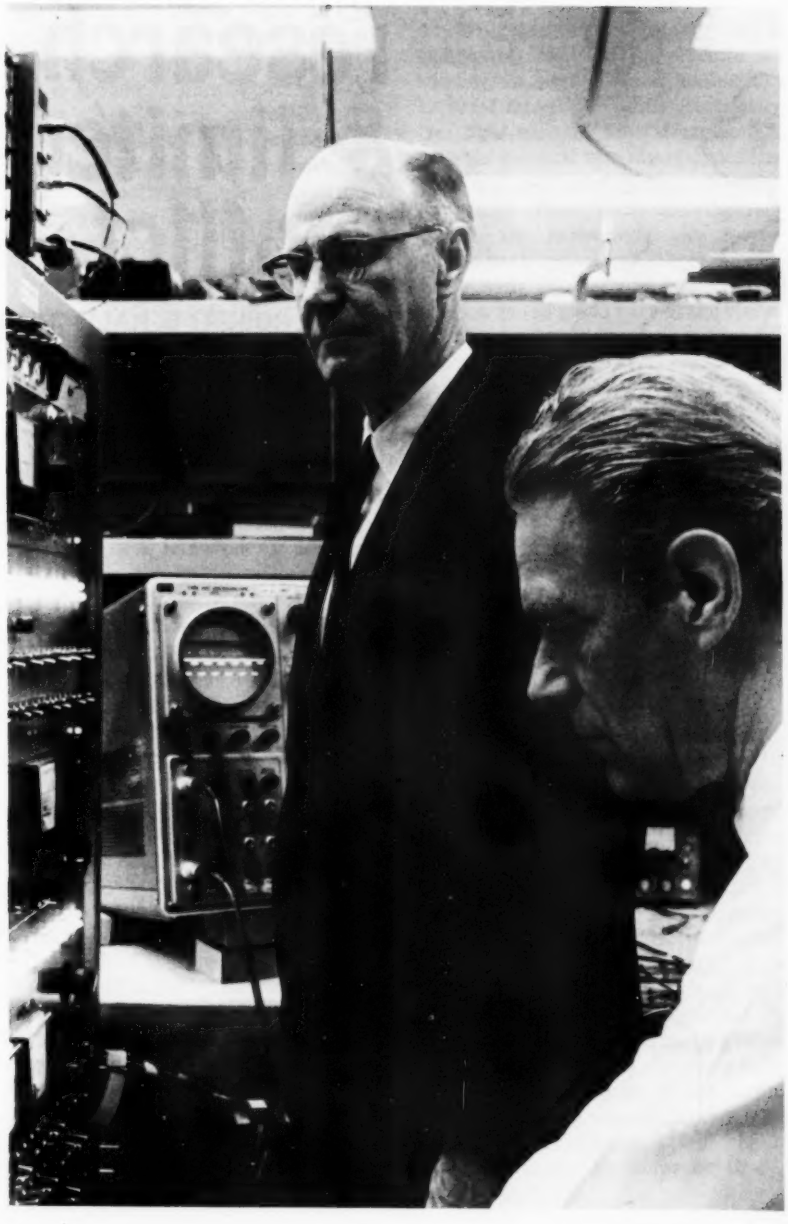
The decoder has a fail-safe feature which makes unlikely the acceptance of any incorrect digits, even on highly degraded channels. Furthermore, it rejects very few words as being uncertain. Although computer simulation of the equipment has been under way for some time, experiments with the equipment itself have already proved the fail-safe decoding capability of the decoding algorithm. Actually, preliminary results have been so encouraging, that already AFSC's Electronic Systems Division has expressed an interest in its further development for future use in Air Force communications links.

Mr. Charles F. Hobbs is Chief of the Information Theory Branch of AFCRL's Data Sciences Laboratory. He is now engaged in work on coding for error correction and other techniques to make communications more reliable in the presence of jamming and interference and propagation anomalies. He received his B.S. in Electrical Engineering from the University of North Dakota in 1930, and his M.S. in Electrical Engineering from the Massachusetts Institute of Technology in 1948.

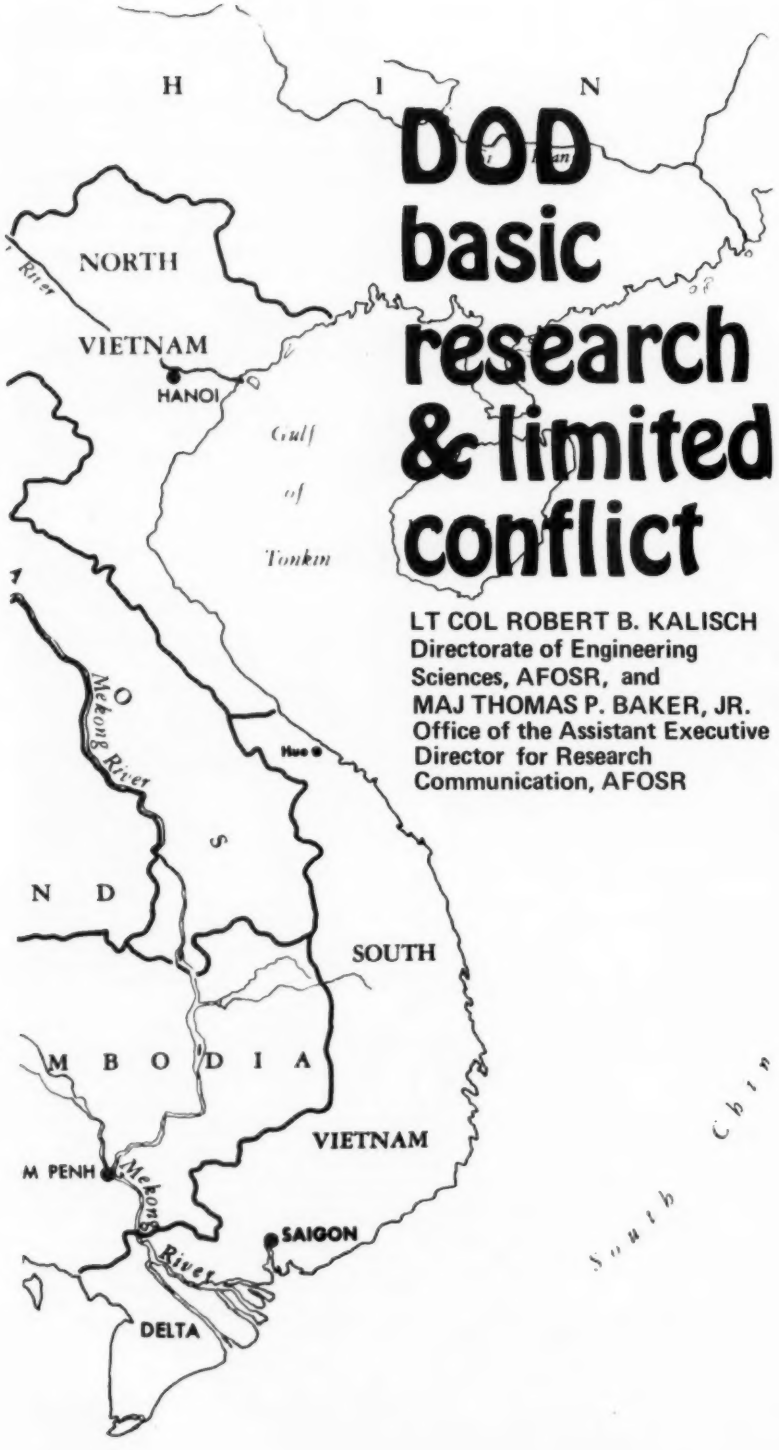
From 1938 to 1945, Mr. Hobbs was employed first by the U.S. Army Air Force Technical Schools as a radio engineer and instructor, and then as a research associate with the Harvard Underwater Sound Laboratory and Systems Research Laboratory, where he did development work on electronic simulators to be used as training devices. Since January 1946, he has been with AFCRL. Mr. Hobbs is the author of numerous publications, and is a member of Sigma Tau, Sigma Xi, RESA, and IEEE.

Mr. Stanwood Ayer is a research electronic engineer (data processing) with the Image Processing Branch of AFCRL's Data Sciences Laboratory. He is now engaged in digital data-processing work as applied to visual data transmission. Mr. Ayer received his B.S. in Electrical Engineering (cum laude) from Tufts University in 1939 and, in 1941, received his M.S. in Electrical Engineering from Harvard.

From 1941 to 1946 before coming to AFCRL, Mr. Ayer was employed by the Boston Naval Shipyard where he worked in the Scientific Section of the Planning Division. He is a member of the Harvard Engineering Society.



Mr. Charles F. Hobbs (left) and Mr. Stanwood Ayer examine new encoder-decoder equipment for error-correcting coding.



DOD basic research & limited conflict

LT COL ROBERT B. KALISCH
Directorate of Engineering Sciences, AFOSR, and
MAJ THOMAS P. BAKER, JR.
Office of the Assistant Executive Director for Research Communication, AFOSR

One of the current critical problems of the DoD basic-research community is to identify and explain its proper role in the light of today's continually increasing emphasis on limited war and the specific problems of Southeast Asia. Increased efforts must be made to illuminate these problems and to intensify research activities as they relate to limited-conflict situations. This paper discusses these activities and gives examples of projects of scientific merit and of clear relevance to Air Force missions in limited-conflict situations.

PROBLEM

In the decade from 1952 to 1962, when total war was the main postulated threat, the Air Force, and indeed the nation as a whole, pursued policies and organized, trained, and equipped to meet that threat. More recent attitudes and policies, and the reality of Vietnam, have combined to force us to look at the whole spectrum of conflict short of total war. That spectrum ranges from the activities of supply and advice under the Military Assistance Program through the intense combat of tactical war. Thus, the Air Force has reoriented its thinking and actions in recent years to give new emphasis to these aspects of conflict. This reorientation has made itself felt throughout the Air Force, in operations, in systems procurement, in development, and indeed in basic research. It is the influence of this reorientation which is the subject of this paper.

OBJECTIVE

To understand the type of relationship which is sought between limited conflict and basic research, one should consider the relationship between general war and basic research during the past 20 years. During this period those fundamental scientific problems which were pertinent to operational military problems received priority treatment. The DoD-supported basic-research program has been keenly tuned to the needs of global war. Research efforts in areas related to high-speed flight, rocket

propulsion, long-range radar, and communications typify the relevant work conducted under this philosophy.

It is now emphasized that the Air Force requires research oriented towards limited conflict as well as research oriented towards global war. A whole new series of weapon systems and devices, and the supporting basic research are required to provide this extended capability. It is in this sense that program realignment and reorientation need to be made.

WHY BASIC RESEARCH?

With the large commitment that has already been made to the problems of limited conflict, one might question the role which basic research can play. Is there some capability which we now lack? Indeed, there are capabilities which are needed for limited conflict: better communication, more accurate firepower, quicker response, and quick identification of insurgents. Moreover, there is a strong conviction in the Government that limited conflicts can be remolded, just as global war has been remolded, by means of basic and applied research. This conviction lies at the heart of the commitment of basic-research resources to limited war.

HOW MUCH?

Just as the military doctrine of a measured response dominates military thinking, the response to limited conflict by the basic-research community must also be controlled. An uncontrolled basic-research effort on limited conflict might cause an unwanted shift of emphasis from other important problems. The Air Force basic-research program, to be of long-range value, must be broadly based in the various scientific disciplines. In this way it eventually contributes to the growth of technology and assures mission relevance.

BASIC RESEARCH FOR LIMITED CONFLICT

The essence of basic research is scientific inquiry into fundamental problems. A scale of the pertinence of these fundamental scientific problems to DoD interests can be defined. Some of them may be closely related and some hardly at all. Some of the problems may seem to be urgent from one point of view and less critical from another. If one considers the fundamental problems whose solutions are most urgently needed to treat the problems of limited conflict, then one has a starting point for the relationship of basic research and limited conflict.

The task is to identify the scale of pertinence to limited conflict for those fundamental problems which we may consider. By concentrating on those fundamental problems which relate most directly to limited-conflict situations, the research community can make significant contributions to their solution. One can easily propose, e.g., that for electronics and electrical engineering two relevant and fundamental areas embrace "detection" and "detectors."

IMPROVED DETECTORS

Several interesting examples of this type of research may be found in the current basic-research program in electronics. One concerns the Harvard Engineering and Applied Physics Laboratory work on cadmium-fluoride detection mechanisms. Specifically, this research was intended to provide a more complete understanding of the photon excitation of rare-earth-doped cadmium fluoride at liquid-helium temperatures. The investigation gave rise to the concept that, in such a material, regions could be created which acted as if they contained free electrons. The free electrons could be excited by incident infrared photons so that the electrons would travel from one excess-free-electron region to another. As this process occurs, the conductivity of the cadmium-fluoride sample changes. The change in conductivity provides a mechanism which can be used as a detection device. This photoconductive effect occurs over a broad range of wavelengths from the visible to 20 microns, takes place very rapidly (on the order of a microsecond), and has the potential for sensitivity variation by changing the dopant level. This new type of detector offers considerable promise in the solution of limited-war problems in that it may lead to scanning detectors using the rapid response, or differential detection devices using wide-band response characteristics.

Another basic-research project that shows promise of assisting in limited-war problems is a solid-state image converter being developed at the Co-ordinated Science Laboratory, University of Illinois. The intended use of this device is to convert infrared photons into visible photons. A narrow-band gap semiconductor such as n-type germanium is placed on a cadmium-sulphide crystal with an insulating layer of silicon monoxide. Incident infrared photons create electron-hole pairs in the germanium. A suitable external bias disassociates the electrons and holes causing the holes to tunnel through the silicon monoxide. On penetrating the n-type cadmium sulphide, the hole recombines with an electron and emits a photon in the green part of the visible spectrum. An attractive feature of such a device is that focussing can be accomplished by conventional optics. Current progress on this project by Dr. W. D. Compton indicates that, in practice, an image intensifier may be required and that thin-film technology may provide the best realization of the required geometry. The essential feature of the research remains unchanged in that real-time infrared displays would be feasible.

RELEVANCE

Both of these projects are basic-research efforts which are pertinent to the detector problems of limited conflict. The identification of such applications and increased emphasis on such projects are the tasks of each project scientist. The requirement is not one of devising new programs vastly different from those of the past, but rather the recognition of those fundamental problems which are pertinent to limited-conflict situations and an emphasis on research related to them. In this manner, by recognizing and taking advantage of the appropriate research opportunities, the basic-research scientist will be able to help solve the problems of limited conflict.

balloon that performs like a parachute

AEROSPACE INSTRUMENTATION LABORATORY, AFCRL

A plastic balloon which performs like a parachute, and which is designed for ejection by small meteorological rockets from high altitude, has been developed by AFCRL. The balloon system, known officially as the STARUTE (Stabilization and Retardation Parachute), is designed to slow the descent and to stabilize the oscillations of meteorological instrument packages.

After ejection from a meteorological sounding rocket at about 200,000 feet, the STARUTE inflates by ram air pressure. It has a teardrop center section that is surrounded by a 4-sided inflated tube. The STARUTE concept, originated by the Goodyear Aerospace Corporation (and known also by the Goodyear copyrighted name of BALLUTE), was developed for use in meteorological rockets by John B. Wright of AFCRL on the basis of his general specifications. Several Government agencies that use rocketsondes to collect meteorological data have already begun to replace the previously used conventional parachutes with the STARUTE.

What led to the development of the STARUTE was the historical experience of periodic signal dropout in recordings from rocketsondes descending by parachute, resulting in degradation of the measured meteorological data. This signal dropout resulted from pitching or coning of the parachute, as much as 90 degrees at high altitudes after being ejected from the sounding rocket. The STARUTE is impressively oscillation-free (plus or minus 3 degrees) along its descent path. Compared with conventional parachutes previously used, the STARUTE has relatively slow and highly uniform descent velocities. The descent rate decreases from 230 feet per second at 180,000 feet to 40 feet per second at 100,000 feet. This is important in temperature measurement since a slower descent velocity must be maintained to avoid excessive aerodynamic heating and the distortion of temperature data.

The STARUTE is part of a comparatively new miniaturized sounding system carried aloft to 200,000 feet by a 2-element LOKI-Dart meteorological sounding rocket. It can be rail-launched in winds up to 30 knots. The Dart system also represents a considerable saving in that it is produced at half the cost of the ARCAS sounding rocket it replaced.

AFCRL's meteorological sounding rocket program is directed by Robert Leviton.

Mr. Robert Leviton is Chief of the Vertical Sounding Techniques Branch of AFCRL's Aerospace Instrumentation Laboratory. Since joining AFCRL in 1953, he has been engaged mainly in the research and development of upper-air sensing equipment. He attended Rutgers University, majoring in mathematics and physics, and received a B.S. degree in 1936. From 1947 through 1949, he studied meteorology at Johns Hopkins University.

From 1940 to 1953, Mr. Leviton was employed by the U.S. Army at the Aberdeen Proving Ground (APG) on ballistic meteorological problems associated with Army ordnance testing. From 1950 on he was Chief of the Meteorological Branch of APG. He is a member of the American Meteorological Society and the American Institute for Aeronautics and Astronautics.

Mr. John B. Wright is a research aerospace engineer with the Vertical Sounding Techniques Branch of AFCRL's Aerospace Instrumentation Laboratory. Since coming to AFCRL in 1960, he has been engaged in work on high-altitude meteorological equipment, including rocket vehicles, balloons, and parachutes. He attended Worcester Polytechnic Institute from which he received the degree of B.S. in Mechanical Engineering (Aeronautics) in 1942. He also studied supersonics under Dr. Antonio Ferri at the University of Virginia.

In 1942, Mr. Wright joined the National Advisory Committee for Aeronautics, in the 8-Foot High-Speed Tunnel Section of the Compressibility Division, Langley Field, Virginia, as an aeronautical research scientist. From 1948 to 1950, he was an aerodynamicist at the Boeing Airplane Company in Seattle, Washington. And from 1950 to 1960, he was a co-partner in a private business venture in the state of Maine.

Mr. Robert Leviton (left) and Mr. John Wright inspect a model of the Dart system used to carry the STARUTE aloft.

ANALYTICAL TREATMENT OF THE EXPLOSION PROBLEM

JOHN W. GORESH
Fluid Dynamics Facilities Research
Laboratory, ARL

INTRODUCTION

Performance analyses for an implosion-driven hemispherical hypervelocity launcher such as that under investigation at the University of Toronto (1,2) require extensive numerical data relating to pressure, velocity, density and energy in exploding blast waves. In obtaining a numerical solution to the blast-wave problem, one can assume that the resulting blast shock is strong, that the pressure immediately behind the shock varies inversely as the shock-front radius cubed, and that the profiles of the physical quantities behind the front are self-similar. (3) Also, the simplifying assumption of an ideal, point-source explosion makes possible analytic solutions and allows insight into the general problem of explosions. An approach similar to that of Taylor (4) was followed in obtaining a solution to this problem.

ANALYTICAL APPROACH

In the ideal case of a point-source explosion, the partial differential equations determining the pressure, density, and energy can be reduced to a system of ordinary differential equations by means of a similarity transformation. Further, they can be nondimensionalized in such a way that only one parameter is involved; namely, the adiabatic constant γ. This is done by introducing a new independent variable η defined by r/R where r is the local radius and R is the radius of the shock wave which can be shown to be proportional to t^{α}. Here, α is an arbitrary exponent which, in the case of an explosion, must have the value 2/5 in order to satisfy the energy conservation requirement. Therefore, the solution to the problem in this case is straightforward, requiring only the integration of a system of three ordinary differential equations.

The system of ordinary differential equations which must be solved is the following:

$$-A(\eta \phi'_1 + 3/2\, \phi_1) + \phi_1 \phi'_1 + \frac{P}{\rho_0 \psi} f'_1 = 0 \qquad (1)$$

$$\psi' \phi_1 - A\eta\psi' + \psi (\phi'_1 + \frac{2\phi_1}{\eta} = 0 \qquad (2)$$

$$A (3f_1 + \eta f'_1) + \frac{\gamma f_1}{\psi} \psi' (-A\eta + \phi_1) - \phi_1 f'_1 = 0. \qquad (3)$$

where the variables f_1, ϕ_1 and ψ are defined as follows:*

$$\text{Pressure} = \frac{p}{p_0} = R^{-3/2} f_1 (\eta) \qquad (4)$$

$$\text{Density} = \frac{\rho}{\rho_0} = \psi (\eta) \qquad (5)$$

$$\text{Velocity} = \frac{u}{U_s} = R^{-3/2} \phi_1 (\eta). \qquad (6)$$

Subscripted quantities were used here in order that the final non-dimensionalized equations would be free of subscripts.

The variables f_1, ψ and ϕ_1 are the similarity quantities representing pressure, density and particle velocity, specifically defined as

$$f_1 = \frac{r^3 p}{p_0}, \quad \psi = \frac{\rho}{\rho_0} \text{ and } \phi_1 = \frac{r^3 u}{U_s}$$

where p, ρ and u are the conditions at the local point, U_s is the shock velocity, and ρ_0 and p_0 are the density and pressure in the undisturbed region, respectively. In the above expressions, primes indicate the derivative with respect to η, the nondimensional radius. This quantity and the speed of sound, a, are given by the expressions

$$\eta = \frac{r}{R} = \frac{r}{At^{2/5}}; \quad a^2 = \frac{\gamma p_0}{\rho_0}.$$

R is the shock radius at time t, and A is an arbitrary constant as yet unspecified. In the present treatment, the actual value of A is unimportant.

Equations (1) through (3) can be reduced to a family with but one parameter γ by the following change of variables:

$$f = f_1 \frac{a^2}{A^2} \text{ and } \phi = \frac{\phi_1}{A}.$$

Substituting into Equations (1) through (3), we obtain the nondimensionalized new equations:

$$\phi' (\eta - \phi) = \frac{1}{\gamma} \frac{f'}{\psi} - \frac{3}{2} \phi \qquad (1\text{-a})$$

$$\frac{\psi'}{\psi} = \phi' + \frac{2\phi}{\eta - \phi} \qquad (2\text{-a})$$

$$3f + \eta f' + \gamma \frac{\psi'}{\psi} (-\eta + \phi) = \phi f'. \qquad (3\text{-a})$$

The above equations must be solved subject to the following boundary conditions:

$$\psi (1) = \frac{\gamma + 1}{\gamma - 1} \qquad (7)$$

$$f (1) = \frac{2\gamma}{\gamma + 1} \qquad (8)$$

$$\phi (1) = \frac{2}{\gamma + 1} \qquad (9)$$

which are obtained by applying the Rankine-Hugoniot conditions at the shock front where $\eta = 1$.

RESULTS

Although closed form solutions of Equations (1-a) through (3-a) are known, they are implicit in form and therefore are not particularly suited to the problem at hand. For this reason, numerical techniques were employed so as to give all quantities explicitly as functions of η. Some of the results of the numerical integration for various values of γ are shown graphically in the figures.

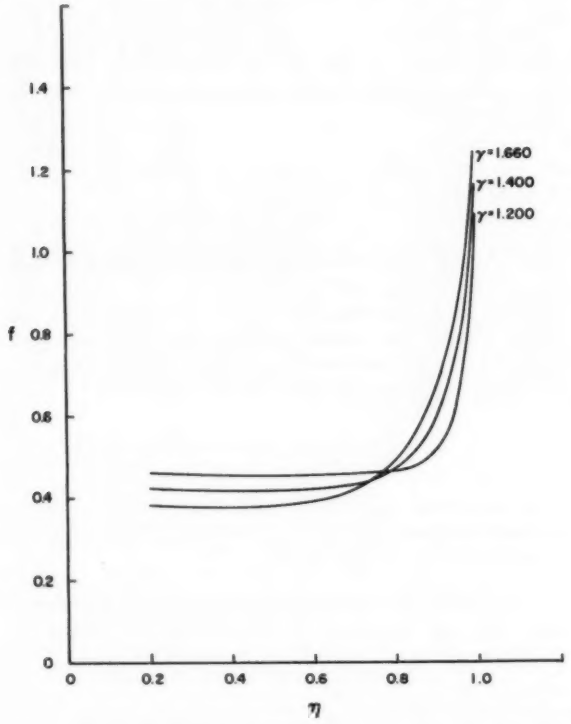


Figure 1.—Similarity variable f versus η for $\gamma = 1.200$, $\gamma = 1.400$, and $\gamma = 1.660$ for a spherical explosion.

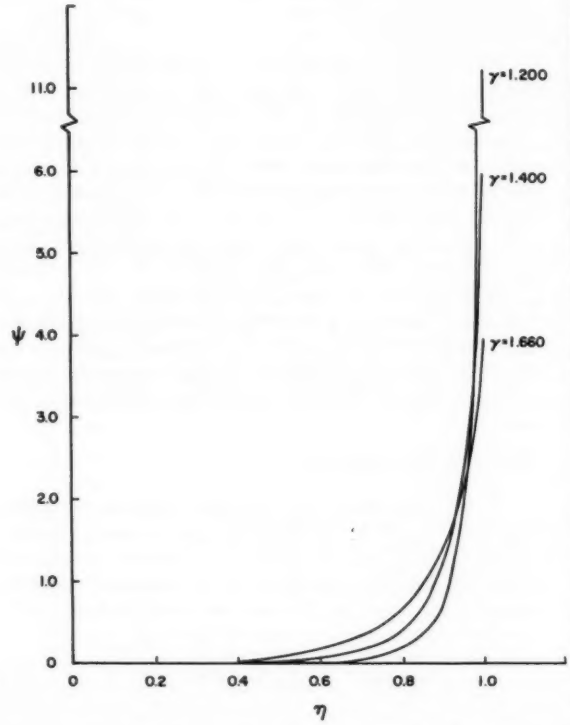


Figure 2.—Similarity variable ψ versus η for $\gamma = 1.200$, $\gamma = 1.400$, and $\gamma = 1.660$ for a spherical explosion.

Mr. John W. Goresh is an aeronautical engineer assigned to the Fluid Dynamics Facilities Research Laboratory, ARL. His current research is in the areas of turbulent heat transfer due to hot gases flowing through small-diameter cylinders, the dissociation of gases at high temperatures and pressures, and the reduction of model data at hypersonic speeds. From June 1960 to November 1962, before coming to ARL, Mr. Goresh was with the Dyna Soar Systems Project Office, Aeronautical Systems Division, AFSC. As Project Engineer under the Dynamics Section, he was responsible for the aerolastic and dynamic-load design for the Dyna Soar vehicle.

Mr. Goresh has a B.S. in Mathematics from Eastern College, Quincy, Massachusetts. He has done graduate work in mathematics, physics, and aeronautical engineering at Boston University, Northeastern University, and Ohio State University, respectively.

CONCLUDING REMARKS

Extensive numerical tables for a wide range of γ are being prepared and will appear as an ARL Technical Report. These will constitute the most extensive tabulations of these important quantities yet compiled.

The problem of an imploding wave is governed by a similar system of equations. In this case the exponent a referred to earlier cannot be determined in such a simple manner. Details of this problem will be the subject of a future note.

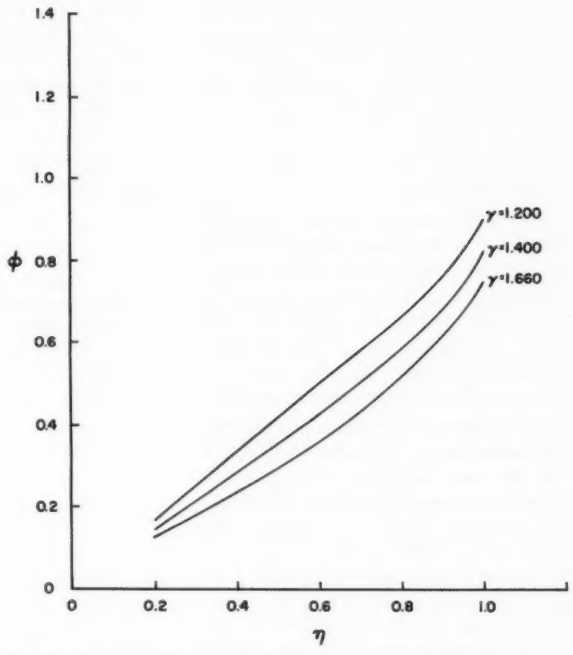


Figure 3.—Similarity variable ϕ versus η for $\gamma = 1.200$, $\gamma = 1.400$, and $\gamma = 1.660$ for a spherical explosion.

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THE GREAT BURST OF MAY 23, 1967

IONOSPHERIC PHYSICS LABORATORY, AFCRL

On May 23, 1967, there occurred one of the most violent and spectacular events ever observed in the solar system. This event was an eruption of matter and energy from the sun on a lavish scale. Intense radio energy over a broad spectrum, a dense flux of high-energy protons, and a solar flare so bright that it was seen in white light were the chief components of the great burst. In the history of solar astronomy, dating back to 1859, there have been only about 20 flares observed in white light.

The great burst reached a peak during a seven-minute interval between 1947 (2:47 p.m. EST) and 1954 UT, with the higher radio frequencies reaching maximum intensity before the lower ones. The time of occurrence gave Western Hemisphere observers a clear overhead view. In addition, satellites recorded high-energy-proton emissions. Few solar events, other than eclipses, have been so thoroughly observed. The burst will surely be referenced in future solar research literature as a standard of comparison.

AFCRL collected more observational data on the event than any other single research organization. The optical instruments at the AFCRL Sacramento Peak Observatory in Sunspot, New Mexico, the radio telescopes and other radiometric equipments at the Sagamore Hill Radio Observatory in Hamilton, Massachusetts, and the 35-GHz telescope (29-foot dish) at Waltham, Massachusetts, were all trained on the sun at the time of the burst.

For astronomers who over the years have lived in daily intimacy with the sun and who know its familiar fluctuating pattern of energies and surface changes, the event of May 23, 1967, had a high drama, but a drama

that is not easy to share with others. In the AFCRL report, "The Great Burst of May 23, 1967" *(AFCRL-67-0622)*, by John P. Castelli and Dr. Jules Aarons of AFCRL, and Capt. Glen A. Michael of the Air Weather Service, the authors describe the events leading up to the great burst:

"Nine consecutive days had passed without a single burst being recorded at Sagamore Hill Radio Observatory. On May 17 and 18, as an extremely hot region began to round the east limb, the total daily flux climbed rapidly. On May 18, 19, and 20, flare-associated burst activity also began to increase, reaching a temporary 'high' on May 21 when, at about 1922 UT, a large complex burst was observed in McMath Plage No. 8818. By the usual standards, the intensity was large. . .The following day, May 22, 1967, was ominously quiet at Sagamore Hill except for one small event at about 1530 UT. On May 23, however, all quiet ceased with events which followed. The first of at least three burst components in McMath Plage No. 8818 reached a maximum at about 1809 UT. . .The second component reached a maximum near 1839 UT. The third component 'peaked' between 1947 and 1954 UT. In the radio portion of the spectrum, the third component was by far the largest. So large in fact was the radio burst that we were inclined to doubt our own calibration."

The calibration for the 5 frequencies at which the burst was recorded at the Sagamore Hill Radio Observatory–606, 1415, 2695, 4995, and 8800 MHz–was verified. No data were lost from "off scale" or receiver saturation. This was not the case with the observations made at 35 GHz with AFCRL's 29-foot antenna. At 35 GHz, the third radio burst began at 1936:40 UT. The trace went off scale at 10,000 flux units. The maximum may have reached 25,000 units. There is nothing in the sparse millimeter literature that indicates burst levels even approaching these intensities.

A major magnetic storm associated with the great event took place on May 26. The storm was one of the largest on record. Auroras were observed on May 25 as far south as latitude 32 degrees N (Georgia).

The AFCRL astronomers conclude that "There can be little doubt that the microwave radio burst of May 23, 1967, was among the largest events ever recorded." Just how the associated optical events would rank among large optical flares, however, is uncertain.

Mr. John P. Castelli is a supervisory research electronics engineer with the Radio Astronomy Branch of AFCRL's Ionospheric Physics Laboratory. He received an A.B. (cum laude) in Romance Languages in 1938, and an M.A. the following year, both from Boston College in Newton, Massachusetts.

As chief of the Solar Section Radio Astronomy Branch, Mr. Castelli is in charge of solar radio work within the Branch, and is responsible for establishing and maintaining a solar radio facility at Sagamore Hill for making continuous observations of the microwave radio sun at multiple wavelengths between 1 cm and 1 meter. He is also responsible for incorporating sweep-frequency work into the solar program, and the layout of solar-eclipse projects. In addition, he assists and advises the Air Weather Service in the Space Weather Forecast mission.

Mr. Castelli is currently engaged in a scheme to classify radio bursts by their spectra. He has several publications to his credit.

Mr. John Castelli checks presentation of sun-burst data.

DR. MARSHALL C. HARRINGTON
Directorate of Physical Sciences, AFOSR

a RADAR MAP of VENUS

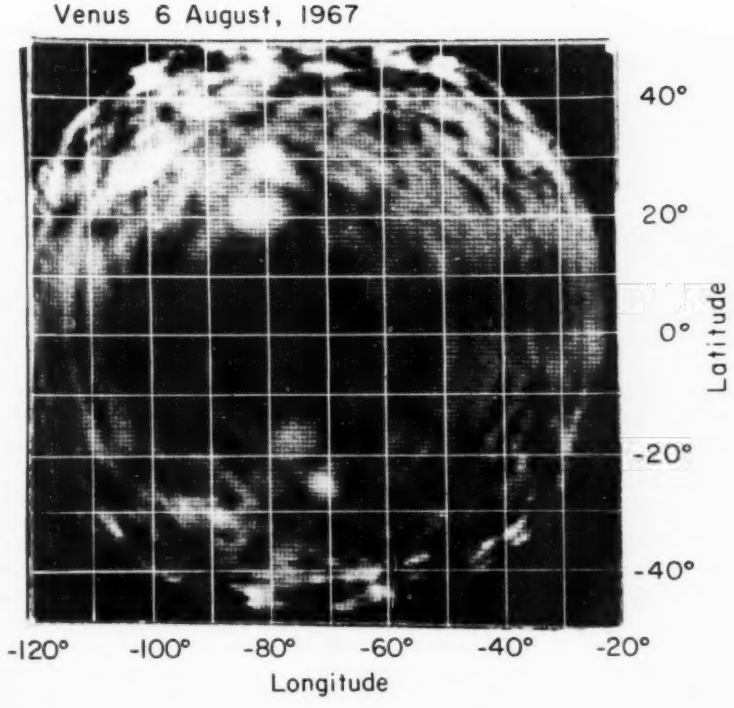


Figure 1.—Radar map of Venus prepared from one of the observations made at Arecibo, Puerto Rico, on 6 August 1967.

A radar map of Venus (Figure 1) has been prepared by Cornell University astronomers using the world's largest radio-radar telescope at Arecibo, Puerto Rico. Since the surface of Venus is continually obscured by clouds, optical telescopes cannot reveal any details. The radar beam at 420 MHz of the Arecibo Ionospheric Observatory penetrates this layer. Range-Doppler techniques permit the constructing of a map by the use of a computer and a cathode-ray display tube similar to that employed in a television set. The resolution is about equivalent to that which would be possible with the largest optical telescope, the 200-inch telescope on Mt. Palomar, if that telescope could observe the surface of the planet.

The diagram in Figure 2 illustrates the technique being used. The whole of the planetary surface is illuminated by the radar beam. The side of the planet rotating toward the earth returns a Doppler-shifted frequency higher than the transmission frequency. The side of the planet rotating away from the earth reflects a lower frequency. Incidentally, the change in frequency, called the Doppler shift, permits a calculation of the period of rotation which, until recently, was not known.

Measurement of the time elapsed between transmission and return of the radar signal provides highly accurate range (distance) information. Analysis of these factors establishes two limited planetary areas, one in the northern hemisphere and one in the southern hemisphere, (P_1 and P_2, for example) which exhibit the same range and frequency characteristics. Since the angular width of the radar beam is larger than the angular diameter of the planet, these two points cannot be distinguished from one another in the analysis. Because of this, the map appears to be reflected about a slightly slanted line near the equator.

Measurements were made at the Observatory in 1964 and 1967 when the planet was closest to the earth during those years. This distance is about 26,000,000 miles. The present map pertains to about one third of the surface of the planet; additional obser-

vations will permit mapping of the whole planet.

There appear to be some rough areas which may be mountains. In general, however, Venus has a smoother surface than does the moon. The average radar reflectivity of Venus is higher than that of the moon, indicating that the planet's surface is probably composed of a denser material than that of the moon. Continued observation of the planet by radar methods will permit improved accuracy in determining the period of rotation of the planet. After many years have elapsed, the period will be known to a degree of accuracy comparable with that of Mars which has been under observation by optical telescopes for hundreds of years.

The delay-Doppler mapping technique was perfected by Gordon H. Pettengill and Rolf B. Dyce at the Arecibo Observatory. It has also been used for detailed mapping of the moon.

The Arecibo Ionospheric Observatory employs a 1,000-foot "dish" for investigations in ionospheric physics, and radar and radio astronomy. It is operated by Cornell University under a contract funded by the Advanced Research Projects Agency and monitored by the Air Force Office of Scientific Research.

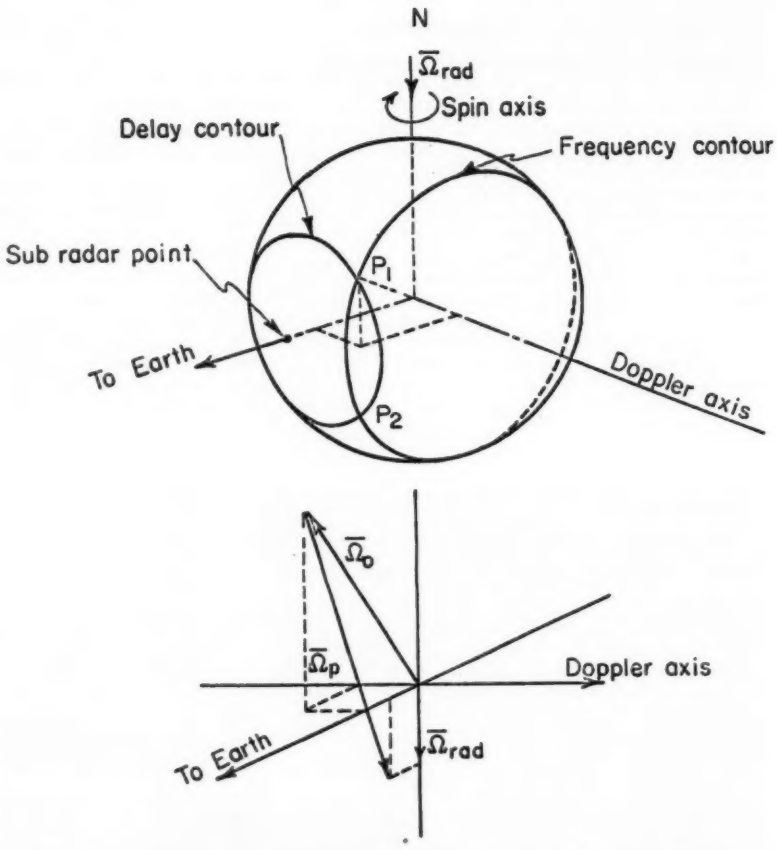


Figure 2. Geometry for the delay-Doppler mapping of Venus. $\overline{\Omega}_0$ is the orbital component of the apparent rotation vector; $\overline{\Omega}_p$ is the intrinsic spin vector of Venus; and $\overline{\Omega}_{rad}$ is the apparent spin vector as seen by the radar.

a hybrid data-acquisition and control system for a hypersonic wind-tunnel complex

1ST LT RONALD L. HAUGEN
Fluid Dynamics Facilities
Research Laboratory, ARL

The value of high-speed wind-tunnel testing is directly related to instrumentation-system accuracy and reliability. The cost per test is extremely high and, quite obviously, retesting boosts costs even higher. Thus, it is important to gather accurate and precise data on every test. In hypersonic wind-tunnel testing, the loss of any channel of information may result in complete failure to achieve the test objectives. It is characteristic of a typical data system that, once data is recorded (on digital magnetic tape), it must be delivered to and processed at a remote computer facility. It is here that the test engineer encounters delays in receiving his test data. Projects become delayed, man-hours are wasted, and costly retesting becomes commonplace. Moreover, such a data system is unable to provide automatic and programmable feedback for on-line controls.

This report capsulizes the development of a facility which encompasses the entire data-handling and processing activities for the Fluid Dynamics Facilities Research Laboratory. Several aspects of current wind-tunnel data-acquisition techniques are discussed including the utilization of hybrid computing equipment to provide direct real-time print-out and CRT display of raw data, or present measurements reduced in terms of their appropriate units.

The major objective of the data system is to provide a capability for data acquisition, data reduction and on-line control in a hypersonic and gasdynamics test facility. Specifications for this system are as follows:

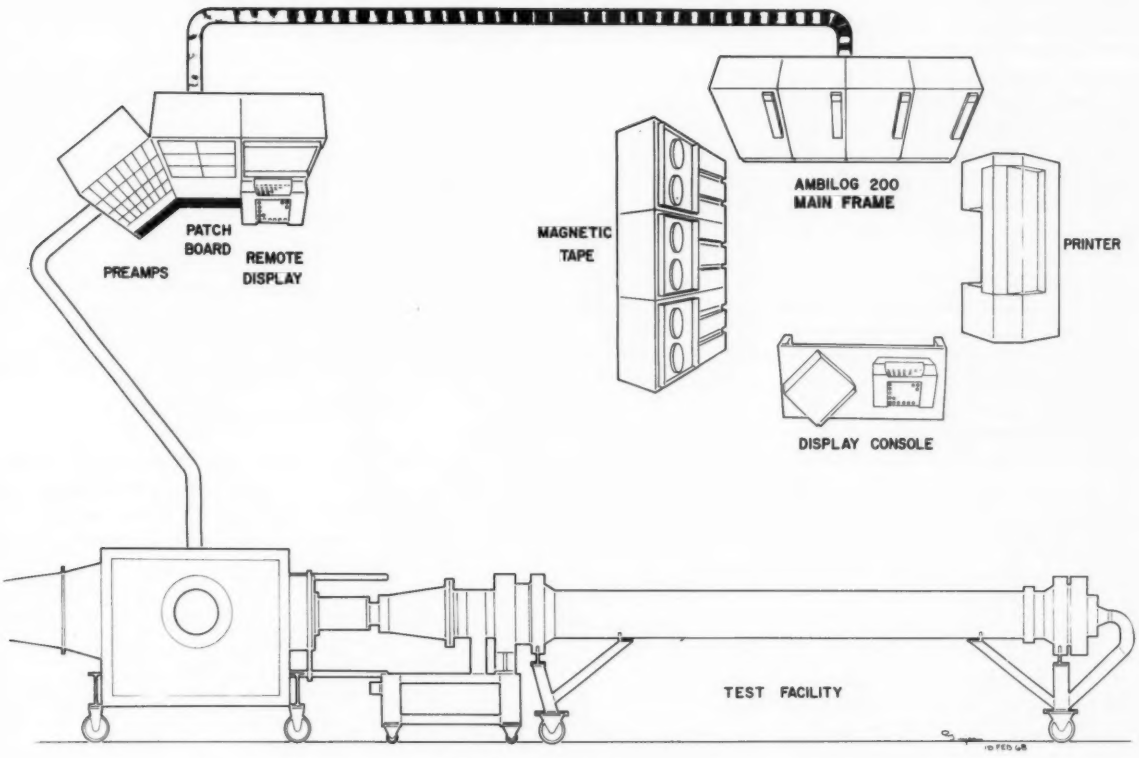


Figure 1. Data-acquisition system.

1. The data system must have provisions for acquiring data from a multitude of analog and digital lines, for operating on the data in a controlled and flexibly programmed manner and, subsequently, storing the data for future reduction.

2. It must possess the capability of modifying the data, if desired, using its own arithmetic calculating capabilities.

3. It must have the power to generate control variables from the input data, these variables to be used in a number of programmable feedback loops.

4. It must possess, either inherently or through the programming system, the ability to work in close coordination with a diversity of gasdynamics test facilities, such as hypersonic wind tunnels, compressor testing devices, supersonic combustion test facilities, and the numerous diagnostic tools and transducers commonly used in such facilities.

5. In connection with the mission of this Laboratory, the system must have a flexibility of operation which will permit its use as an experimental device within itself.

6. Equipment setup times must be minimal and high system throughput rates must be provided.

To meet these specifications and the requirements of numerous and varied experiments, a hybrid configured system was developed specifically tailored for data acquisition and signal processing. This system combines the high-speed parallel arithmetic capability of analog computing elements with the precision and logic capabilities of a high-speed digital central processor.

In the data-acquisition mode the system is capable of accepting up to 128 channels of low-level signals. The high-speed analog elements are switched in synchronization with a high-speed multiplexer so that incoming data can be operated on in analog form. The data is then digitized, putting it in a form best handled by a digital sequential processor for routing into recording and/or display channels. (The analog-to-digital converter is a 15-bit binary unit which can give a resolution of 0.01% of full scale.)

While hybrid machines are not unique in general, most require that data be digitized, classified, and then reconverted to analog form before being operated on by the analog section. Hence, in those cases, execution speed is still limited by the speed of the digital section. As an example, the current data system can sample an analog input, x, perform the operation $y = mx + b$, then digitize the operation and store y within the space of 18 microseconds. The typical digital processor would require 40-50 microseconds for the same operation.

Data output is obtained via a high-speed printer, both on-line and off-line, depending upon the volume of data. Input of data-control programs and other software is

accomplished via typewriter, paper tape, magnetic tape, and a display oscilloscope-light pen. Analog outputs can be obtained for display or recording via oscilloscope, x-y plotters, and oscillograph.

Off-line, the computer may be used as a data logger for calibration of the transducers and signal-conditioning equipment displaying values in their true engineering units or values, for computation of scientific equations, or for further data analysis. Thus, the hybrid computation concept allows the system to acquire data under virtually any specified sampling sequence and at gains specified by the operator.

Digitally, the computer has 32,784 words of memory, assuring the user of sufficient capability to store the various data and operating programs required for the real-time reduction of data to engineering units for print-out and display. The system includes 3 digital magnetic-tape drives. One is utilized primarily as a program input device. The others serve as output devices for recording raw data, performing off-line data reduction, and data editing.

The off-line program is designed to interface with the on-line program. Any functions performed by the on-line program, including ASA Standard FORTRAN, may be requested by the off-line user. Additionally, all programs, system-operating and scientific-computing, are stored on magnetic tape and controlled by a resident monitor.

In summary, the data system provides a vastly improved and technically advantageous instrumentation and data-handling capability. Its advanced data-collection and control routines, simulation and modeling capabilities, and general system development enhance its usefulness as an aid to experimental gasdynamics. Simultaneously, the unique hybrid configuration provides a flexibility of operation which permits its use as an experimental device within itself.

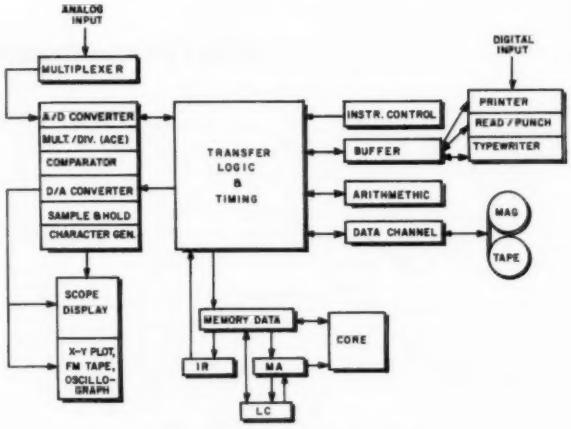


Figure 2. Data-system organization.

1st Lt Ronald L. Haugen has been an aeronautical engineer with the Fluid Dynamics Facilities Research Laboratory, ARL, since 1966. In his current research he is investigating high-performance turbomachinery along two lines: first, he is making an annular cascade study to determine the feasibility of mechanically accelerating high-pressure air to unusually high total temperatures for use in hypersonic wind tunnels; and second, he is conducting two-dimensional cascade studies in support of current efforts in the development of efficient supersonic compressors.

Lt Haugen received his B.S. in 1962, his M.S. in 1963, and his Ph.D. in 1966, all in Mechanical Engineering and all from Michigan State University. He has several publications to his credit.

new crystal-growth facility

SOLID STATE SCIENCES
LABORATORY, AFCRL

Mr. Charles Ryan (left) and Mr. Robert Marshall examine a crystal of silicon carbide grown in AFCRL's new furnace.

A new system for growing single crystals of ruby, silicon carbide, transition-metal silicides, and other materials under a range of experimental conditions, has been placed in operation at AFCRL. The system is designed around the conventional Czochralski crystal-growing technique. To this technique has been added a number of refinements permitting better control of the growth environment.

The furnace-system concept and specifications were set forth by Robert C. Marshall and Charles E. Ryan of AFCRL. The furnace system itself was built for AFCRL by A. D. Little, Inc. Among its novel features are the precise control of temperatures over a range of 1,500 degrees C to above 3,000 degrees C, and pressurization and vacuum systems which permit crystals to be grown in a chamber either pressurized as high as 300 pounds per square inch or evacuated to a pressure as low as 10^{-5} torr.

The conventional Czochralski method of crystal growth is one that starts with a crucible of molten material maintained at high temperatures by induction-coil heaters. A small seed crystal is lowered into the molten material which solidifies onto the seed as it is slowly withdrawn—about an inch or so an hour.

In growing compound single crystals (as against elemental crystals, such as silicon) by this method, difficulties arise, with each compound providing its own set of peculiarities. One constituent of the compound is normally more volatile than the other, resulting in excessive vaporization and possible nonstoichiometry (an imbalanced ratio of elements) in the

crystal. Many problems can be controlled in the AFCRL furnace by growing the crystal either in an inert gas under pressure or, conversely, by growing it in an evacuated chamber. Other problems arise because of inadequate control of furnace temperature. One feature of the AFCRL furnace is a high-pressure water-cooling system for controlling wall temperatures, permitting operation without internal shielding. A method for measuring temperatures relatively accurately above the 3,000 degrees C level has been devised for use in the furnace.

The new system will permit AFCRL crystal growers to grow a great variety of crystals under a range of experimental conditions not previously possible. The ultimate goal is to grow crystals with improved properties for electronic- and optical-device application. The system is described in detail in the AFRCL report, "High-Pressure, High-Temperature Crystal-Growth System" *(AFCRL-67-0656)*, by Robert C. Marshall.

Mr. Charles E. Ryan is Chief of the Semiconductor Physics Branch of AFCRL's Solid State Sciences Laboratory. His major current activities deal with investigations of the growth and properties of wide-band semiconductors and semi-insulating crystals.

Mr. Ryan has a B.A. from Boston College (1933), and a B.S. in Electrical Engineering from M.I.T. (1937). He also has graduate credits in electronic engineering, solid-state physics and mathematics from M.I.T., Northeastern University, the University of Illinois, and Columbia University.

Mr. Ryan joined AFCRL in 1948 when he was first put in charge of an infrared communication project. In 1949, together with Dr. E. W. Samson, he initiated the solid-state-research program at AFCRL and a miniaturization program associated with a classified project. He is a member of the Institute of Radio Engineers, the Optical Society of America, and the Research Society of America, and has authored several publications.

Mr. Robert C. Marshall is a physicist with the Semiconductor Physics Branch of AFCRL's Solid State Sciences Laboratory. He is presently working in the area of single-crystal growth from molten-metal solutions. He has a degree of Bachelor of Electrical Engineering (1948) from the Clarkson College of Technology, Potsdam, New York.

In 1949 Mr. Marshall joined the Wright Air Development Center, Wright-Patterson AFB, Ohio, where he worked on the research and development of electronic-circuit elements. In 1955 he was assigned duties as staff engineer in the Operation Office of the Electronic Components Laboratory. He has been with AFCRL since 1959.

Mr. Marshall is a member of the Institute of Electrical and Electronic Engineers and the Electrochemical Society, and is the author of several publications.

AUTOMATED FIELD STATION FOR MONITORING SOIL PROPERTIES

TERRESTRIAL SCIENCES LABORATORY, AFCRL

An automated, unmanned field station for the remote monitoring of soil moisture and soil strength has been developed by AFCRL and the U.S. Army Engineer Waterways Experiment Station. The station is designed for unattended operation for more than a year. Data are telemetered to a central station either by land lines or by radio. The Army is now testing the station in the Vicksburg, Mississippi area. Later this year, AFCRL will test the automated field station in the northern Mojave Desert near Edwards AFB in California.

The Army is interested in the weight-bearing properties of soils from the standpoint of motor-vehicle traffic. AFCRL is interested from the standpoint of emergency air operations. Most locations that are normally suitable as natural runways can become temporarily inoperable when rainfall alters the weight-bearing properties of the soil.

The automated field station is designed to furnish the following kinds of information: soil strength, soil-moisture content and temperature, wind direction and velocity, and air temperature. The station can be easily transported by truck for installation. Essentially, the station is an augmented version of the commercially available automatic weather station manufactured by Berkeley Instruments Corporation of Oakland, California. To the meteorological sensors of the station, AFCRL and the Army have added soil-moisture and soil-strength sensors. The soil-moisture sensors are of the electrical-resistance type which are placed at various depths beneath the surface of the ground. Because these sensors are subject to corrosion, AFCRL is also testing a modified version of a commercial neutron moisture meter.

The most important and difficult measurements made at the station are those concerned with soil strength. For the measurements, a self-propelled, track-laying tractor, about four feet long and three feet high, carries a cone penetrometer which is pressed

into the soil to various depths by means of a hydraulic system. The cone penetrometer is simply an instrument that tests the penetration resistance of the soil. The tractor is guided along a prescribed spiral path by a cable attached to the central station mast. Its radius of travel is selected according to the site topography, and it makes a programmed sequence of measurements at several locations. When a rock is encountered or the recorded data are outside realistic limits, the tractor will move to another location and begin a new sequence of measurements.

Power for the entire station is provided by a propane-burning thermopile with 2 watts' continuous output. About 100 gallons of propane are needed for a year's operation.

Mr. Carlton E. Molineux is a physicist with the Geotechnics Branch of AFCRL's Terrestrial Sciences Laboratory. He is now engaged in the development, test and evaluation of techniques, instrumentation, and criteria to meet long-range military needs for worldwide earth-physics programs. He has a B.S. in Physics with honors (1939) from Northeastern University, and an M.S. in Physics (1941) from Boston University.

Since joining AFCRL in 1950, Mr. Molineux has served in several capacities in the fields of arctic studies, soil science, and terrain research. He has pioneered in the development of air-droppable instrumentation for the remote determination of surface properties, and in the development of standards for aircraft operation on natural terrain in arctic regions.

Mr. Molineux is a member of the American Institute of Physics, the Soil Science Society of America, RESA, the American Polar Society, and the Earth Science Technologies Association. He is the author of a number of papers.

Mr. Molineux checks a cone penetrometer used to test soil-penetration resistance.

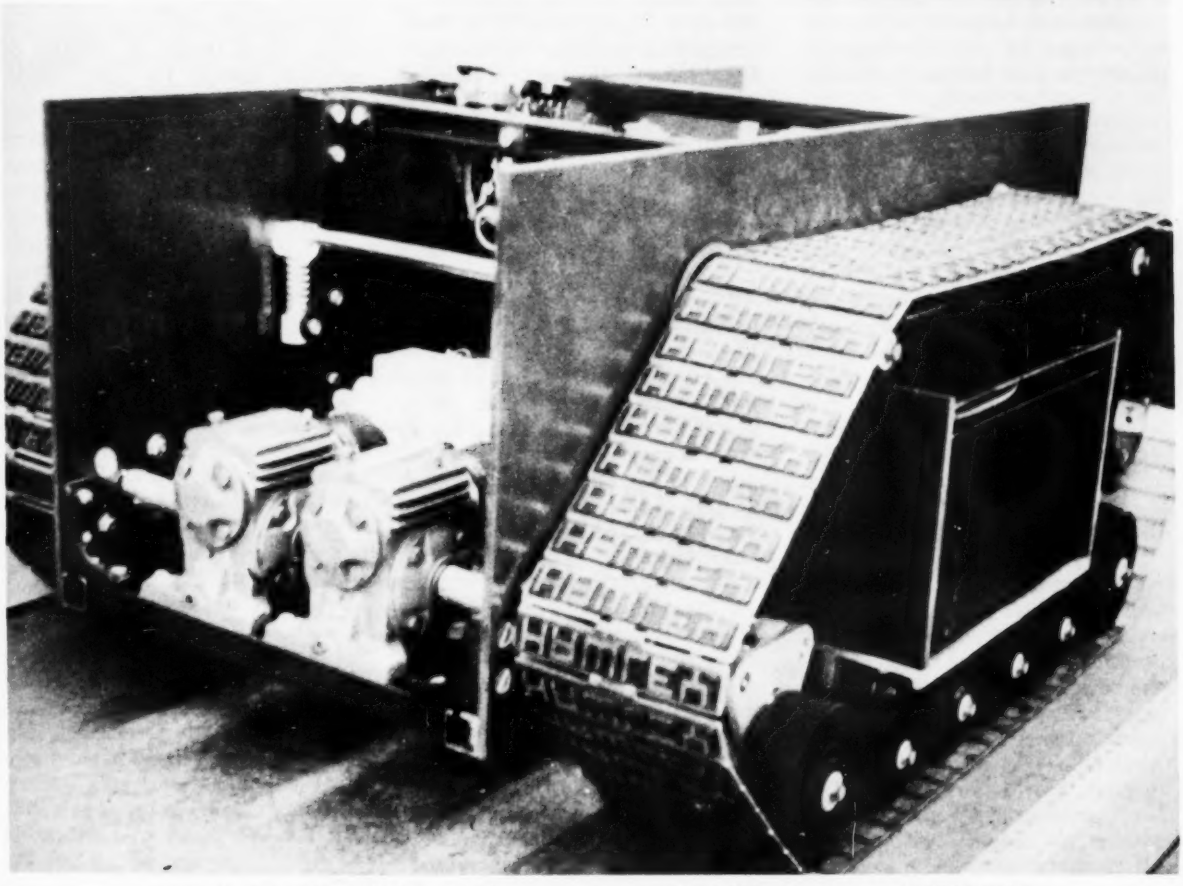


Figure 1.—The self-propelled, track-laying tractor used at the AFCRL-Army automated field station.

OPCOUSTIC

CAPT JOHN F. KANTAK

Directorate
of Engineering Sciences, AFOSR

The interaction of optical and acoustic energies at ultrasonic frequencies has been investigated by scientists for the past five decades. This phenomenon is an example of Brillouin scattering. Until recent technological breakthroughs, it has been impossible to effect this interaction at microwave frequencies with an acceptable degree of efficiency. The Microwave Laboratory at Stanford University, under the directorship of Dr. Marvin Chodorow, is investigating the phenomenon. This investigation is sponsored by the Air Force Office of Scientific Research through the Joint Services Electronics Program (JSEP).

Brillouin scattering, the diffraction of light by elastic waves traveling in optically transparent liquids and solids, was predicted as early as 1922. Since then, considerable effort has been devoted to exploring the phenomenon using ultrasonic-frequency elastic waves.

The term, "elastic," is related to the ability of a material to regain normal geometry subsequent to a physical deformation. In essence, this describes the performance of matter stimulated by an elastic wave. The energy of an elastic wave moves from one point to another, within a material, *without* the transfer of matter. The wave propagates via the pressure-induced local motion of the molecules. When the elastic energy is removed from a group of molecules, they return to their normal unstressed positions. Elastic energy traveling through a crystal at the speed of sound is called an acoustic wave. Within the constraints of this presentation the phrase, acoustic wave, will mean the transfer of microwave-frequency elastic energy through a crystal at sonic velocities.

As mentioned previously, there were difficult problems to overcome before the scattering phenomenon could be explored with the use of microwave frequencies. Power attenuation was, and still is, the most significant factor in the performance of an optical-acoustic experimental apparatus. Originally, all but a fraction of one percent of the electrical input energy was lost while attempting to couple the signal into a suitable crystal. Propagation through the crystal caused a further reduction in the available acoustic power. The cumulative effects of power attenuation can result in so small an amount of acoustic energy for the optical-

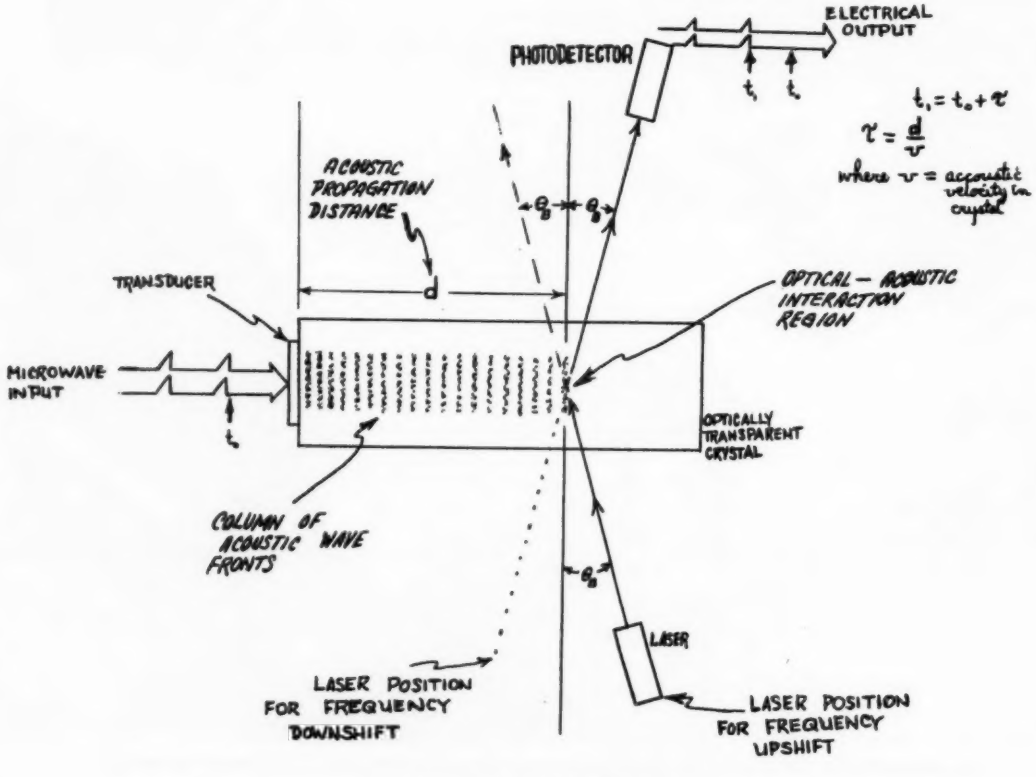


Figure 1.—Bragg diffraction system.

acoustic interaction that no significant optical effects are observable. However, microwave research interest in Brillouin scattering has been stimulated during the last few years by three scientific advances. These achievements were: (1) the demonstration of efficient methods for exciting coherent acoustic microwaves in optically transparent crystals; (2) the discovery of materials and techniques for the low-loss transmission of coherent acoustic waves in crystalline structures; and (3) the growth of laser technology, which provided coherent optical sources.

As of the mid-1960's it was practical to suggest the investigation of Brillouin scattering with the goal of achieving utilitarian microwave devices. The early work at Stanford, sponsored by JSEP, provided one of the first systematic and quantitative studies of light diffraction by acoustic microwaves. Material characteristics, diffraction efficiency, and frequency bandwidth were defined for a variety of crystals and found to be in accord with the theory. These data provided the information required to define the avenues which exhibited the greatest promise for practical systems, and enunciated the potential of Bragg diffraction.

Bragg diffraction is used to obtain the maximum intensity of diffracted (Brillouin-scattered) light energy. The Bragg angle (θ_B) is the angle that the light beam makes with the acoustic wave fronts such that maximum diffraction occurs. At microwave frequencies θ_B is in the range of a few degrees. The basic elements of a Bragg diffraction system are shown in Figure 1.

A microwave-frequency electric signal is applied to the transducer attached to the left end of the optically transparent crystal. The transducer, a piezoelectric material, responds to the applied a-c voltage and sends a mechanical vibration (acoustic wave) into the crystal. The coherent light beam of the laser impinges on the acoustic wave fronts, and the bent or diffracted light energy is detected by a photodetector. The photodetector changes the optical energy into an electrical output that is proportional to the intensity of the acoustic wave.

The acoustic energy causes periodic local distortions in the crystal density by forcing the molecules closer together, away from their normal positions. This results in changes in the optical dielectric constant which causes the diffraction of the laser-light energy. The greater the acoustic energy, the more optically diffracting the crystal becomes. Therefore, the diffracted energy enters the photodetector with an intensity proportional to the intensity of the acoustic wave, and the output of the photodetector contains any amplitude modulation present in the acoustic wave. For example, if the input energy is a series of pulses, then the output of the photodetector will be a series of pulses whose intensities are proportional to the intensities of the input pulses.

It is interesting to note that the frequency of the diffracted light is shifted from that of the incident light by an amount equal to the frequency of the acoustic wave. The frequency change is like a Doppler shift. If the interaction occurs as shown in the figure, the diffracted-light frequency is upshifted. If the laser light followed the dotted line, then the shift would be downward. Regardless of the direction of the frequency shift, the change is always equal to the acoustic-wave frequency.

Another interesting facet of this system is the variable time delay it provides. The acoustic wave must travel from the transducer to the area where the laser light traverses the crystal before the diffraction process can occur. The acoustic-path length is denoted by d in the figure. If the positions of the laser and the photodetector are fixed, and the crystal is moved to the left, then d is increased and so is the transit time τ. If the crystal is moved to the right, τ is decreased. Thus the delay between the input and output is mechanically controlled.

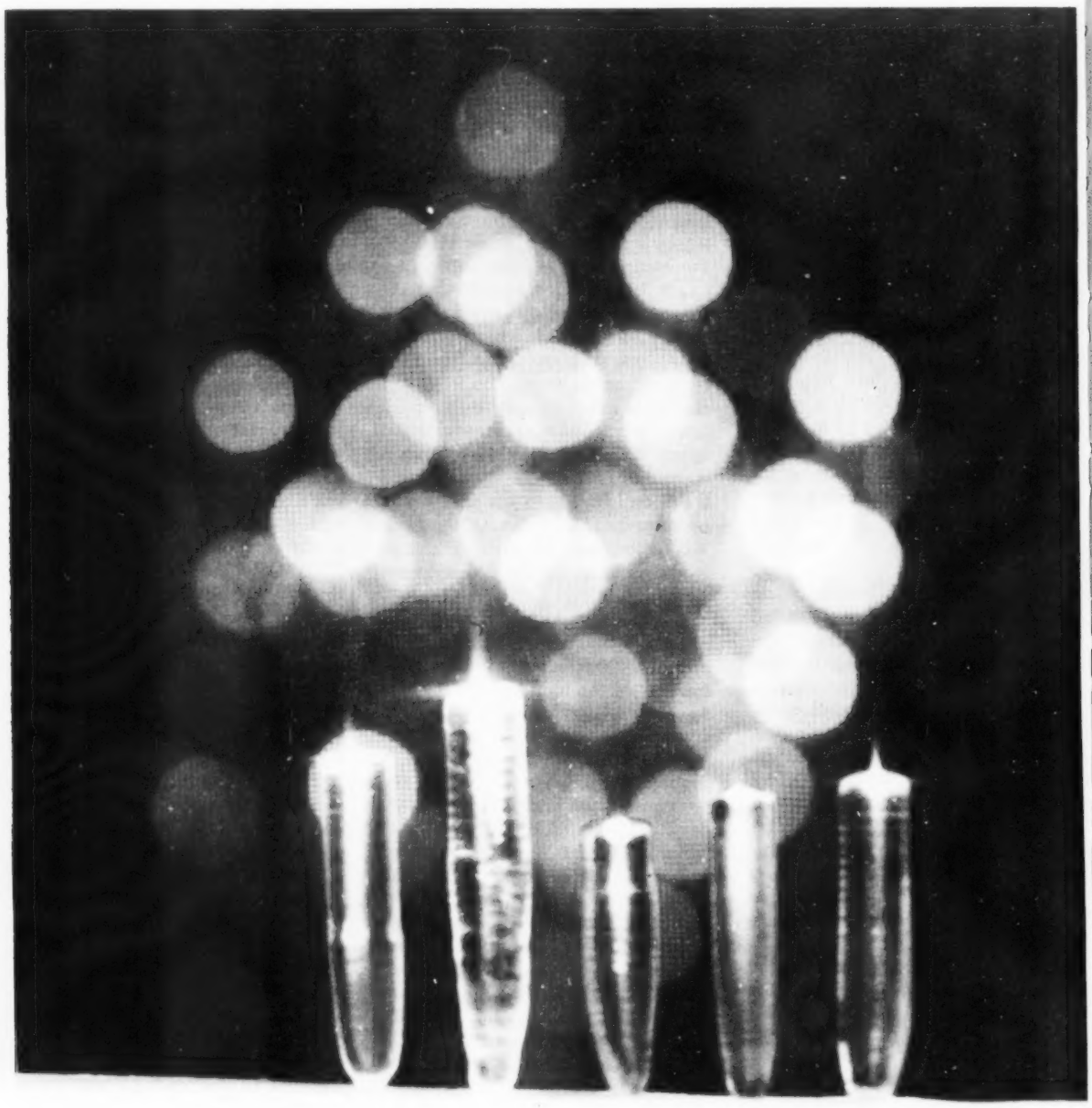
The basic Bragg diffraction system has been described, and the versatility of the phenomenon is evident. Even in the simple form of Figure 1, the system has definite advantages over presently used hardware. Familiar delay lines such as rectangular waveguide tapers, coaxial cables, or strip lines are rather large or hard to adjust, and usually produce a high power loss that is generally offset at some later time by an amplifier system. The entire Bragg diffraction system could take up less room than a desk drawer, it is easily adjusted, and the power loss is much less. This does not mean that all microwave delay-line problems have been solved; but the means for a solution are close at hand. As acoustic-wave transducers are improved, the present power losses will decrease significantly.

A prototype pulse compression system has been demonstrated by the Stanford group. It is an outgrowth of the Bragg diffraction studies and is intended for use in handling complex radar signals which cover a wide frequency range. The microwave input signal has the form of "chirped" radar pulses, which ("chirped") implies that the frequency of the signal varies linearly with time across a pulse. The input signal creates a chirped acoustic wave in the crystal, which causes the diffracted laser light to be focused in front of the photodetector. The focused beam scans across the detector at the acoustic-wave propagation velocity. An optically opaque plate, with a small rectangular slit, is placed at the focal distance of the diffracted light. Only the light which passes through the slit reaches the photodetector, and the received light is a time-compressed version of the stimulating radar input. To date, pulse compression from 1 microsecond to 8 nanoseconds has been achieved. The system is being refined toward achieving a goal of 2 nanoseconds. This figure is significant if we consider that a radar with a 500-megacycle bandwidth and a 2-nanosecond pulse output has a range resolution of 1 foot.

Although all of these concepts are in the embryonic stage, the size, weight, and performance of the systems discussed make extensive investigation very advisable. There is evidence of a potential for applications in microwave and optical radars, secure communications, variable delay lines, acoustic microscope, and countermeasures, to mention but a few.

This AFOSR-sponsored research should contribute significantly to the solution of present and future aerospace problems.

some interesting aspects of AFCRL's crystal-growth program



Several ruby crystals (aluminum oxide doped with chromium) are seen fluorescing in ultraviolet light. AFCRL has five Verneuil furnaces capable of growing such crystals. It also has one of the most complete laboratories for crystal growth in the country.

Shown here are crystals being grown in silica–gel solution. AFCRL grows crystals by this technique in order to study crystal–growth processes at room temperature.

DR. STUART I. FICKLER
General Physics
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constants of the motion in general relativity

One of the outstanding and more difficult problems of general relativity has been that of defining constants of the motion for curved spaces. The significance of these quantities lies in the fact that they are the observables of any physical theory; for example, in classical mechanics, they are the energy, linear momentum, and angular momentum.

In classical theory and in special relativity, these quantities are theoretically defined as the consequence of the symmetry properties of the space under co-ordinate transformations. As an example, if we consider a system such that the equations of motion remain unchanged after a translation of the spatial co-ordinates, then this leads to the conservation of linear momentum for this system (similarly, invariance under spatial rotations leads to conservation of angular momentum and under time translations to conservation of energy).

When, as in general relativity, one goes over to general covariance of a curvilinear space-time, the relationship between symmetries and constants of the motion gets washed out. In fact, in a curved space, global symmetries which satisfy relationships of the sort found in special relativity that lead to the constants of the motion no longer in general exist. In recent years a number of highly significant contributions have been made toward the solution of this problem at ARL by Drs. Louis A. Tamburino and Jeffrey H. Winicour.

In previously reported work, Drs. Tamburino and Winicour have discovered quantities which they called "asymptotic symmetry linkages." Although it is not generally possible to uniquely define energy and momentum in a local region of space-time, it is possible to discuss asymptotic symmetries in the case of asymptotically flat spaces (regions very far from matter or from strongly curved regions of space). The linkages they discovered relate the asymptotic symmetries to physical invariants in a finite region. This result depended on a formalism, also developed by them, which uses light-like or null surfaces in place of the usual space-like co-ordinate surfaces. Thus, by taking limits along the null directions, one can find quantities which are related to the usual concepts of local energy, momentum, and angular momentum.

In the initial development of this work, the theory was carried out so that it was invariant under co-ordinate transformations, which is a necessary requirement of any theory of this type. However, there remained an elusive aspect of the problem which was an obstacle to a fully satisfactory theory. The work was performed in the framework of conformal transformations. These transformations are related to the manner in which an observer takes the asymptotic limit in order to compare invariants. Thus, in order to truly preserve the concept of a constant of the motion, it was necessary to have conformal invariance also. In a recent paper, Dr. Winicour has developed a technique for calculating the total energy, momenta, supermomenta, and angular momenta of asymptotically flat space-times in terms of co-ordinate and conformally invariant expressions by taking the limit of the asymptotic symmetry linkages in an invariant way. The resulting expressions consist of integrals over a sphere at null infinity of co-ordinate and conformally invariant quantities. Thus this most recent work provides a complete theory of linkages which satisfies all of the requirements of general relativity.

The importance of this work is manyfold. Any successful quantization of the gravitational field rests on the ability to define the observables of the theory. Application of the linkages to the structure and dynamics of localized gravitational sources should lead to a better understanding of strong field regions. Furthermore, the techniques developed in this work open a number of new approaches to the treatment of the gravitational field.

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